

PROTON SYNCHROTRONS FOR ENERGIES ABOVE 20 GEV

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Introduction

In the energy range above 20 GeV there is a great deal of effort, a part of which is actually resulting in hardware, but even more seems to be devoted to the production of printed documents. During the past decade there have been so many design studies, proposals, counterproposals, site studies, title I reports, title II reports, formal conference reports, informal conference reports, government reports, and panel reports, that it is difficult to keep them all on file in an office of the usual size.

The program divides naturally into two classifications. On the two proton synchrotrons now operating at energies above 20 GeV, namely the CERN 28-GeV PS and the Brookhaven 33-GeV AGS, extensive improvement programs have been initiated, aimed at increasing both the peak and average beam intensities and at adding to the experimental capabilities of both machines. At CERN this program is in addition to the storage ring construction program which Dr. Johnsen has just described.

The second category of super-energy effort is involved in the design and construction of new accelerators. Most advanced is the 70-GeV synchrotron at Serpukhov in the USSR. Also under construction in the USSR is a 25-GeV proton-antiproton storage ring system designed by the Institute of Nuclear Physics at Novosibirsk. Design studies have reached relatively complete preliminary designs for a 40-GeV machine in Japan, a 45-GeV accelerator in France, and for the American 200-GeV and the European 300-GeV synchrotrons. About still higher energies there is still speculation but no serious proposals.

I now present some details of these various projects and studies.

The PS and AGS Improvement Programs

The programs proposed for improvement of the CERN and Brookhaven synchrotrons are very similar in objectives but differ considerably in detail.

At both laboratories, the first stage in the improvement program involves addition of new power supplies with increased ratings for the main synchrotron magnets. With the new supplies acceleration to full energy will be possible in about one-half second instead of about one second as is now the case. Also it will be possible to maintain the magnet at full field for periods as long as several seconds to give long beam spills to experiments using counters. This modification will be made with the possibility in mind of greater safety against power supply failure, a plague that has

affected many of the world's large accelerators during the past several years. This insurance will be included in the Brookhaven case, for example, by designing the new power system to include on one shaft a generator, a flywheel, a driving motor, a flywheel and a generator, in that order. If one alternator fails we can run at our present rate on the other alternator. If the 12,000 hp motor fails, it can be replaced by our present 5500 hp motor, which will be kept on standby, and again we can continue to run at our present rate.

The increase in possible rate of acceleration doubles the demands on the radiofrequency accelerating system which now must be rebuilt to the new specifications.

In addition to the increase in possible average intensity due to the increased cycling rate, it is desired at both laboratories to increase the achievable peak intensity by a factor of five or ten. The staffs at CERN and at Brookhaven agree that the correct step in this direction is to increase the energy of the injector which now is a 50-MeV linear accelerator at both centers. At one stage it was agreed that it would be best simply to build a larger linac of perhaps 200 MeV. But injector studies for the super-energy, 200 and 300-GeV machines began to result in a flood of new ideas and inventions and the backwash of this flood began to be felt around the feet of the machine improvers. Most of these schemes involved intermediate synchrotrons of various sorts, some of which were to be cycled rapidly and to inject several times into the main ring for each full energy pulse of the main synchrotron. Others were cycled only once and had their charge extracted over several revolutions of the smaller intermediate synchrotron and so distributed around the greater circumference of the main synchrotron ring. Finally, there was a class of machines with several interlaced orbits. In these schemes magnets were rather thinly distributed around a ring of perhaps a quarter or one-third of the circumference of the main ring. Usually each magnet played a part in at least two of the orbits which circulated about, dodging some magnets and being bent in others. If there were, for example, four orbits, the injector had one-quarter of the circumference of the main ring. After acceleration in the injector synchrotron the interlaced orbits are to be dumped in sequence into the main ring. At first this somewhat fantastic scheme was regarded with favor only by its inventors at CERN and LRL. Recently, however, it has come into considerable favor, particularly at CERN where its use has an effect reflected through the PS into the intersecting storage ring. It has recently been shown by Courant, Keil and Sessler<sup>1</sup> that a material increase in total charge,

or an important reduction in energy spread in the storage rings will be possible if the multi-ring injector is used for the PS. At CERN the new injector for the PS is still under study but a decision can be expected during 1967. At Brookhaven last year we made a study of various injector synchrotrons<sup>2</sup> and concluded that, to meet our schedule of almost immediate construction, we should be conservative and stick to our original 200-MeV linear accelerator injector.

At CERN the improvement program includes additional experimental facilities such as a large heavy liquid bubble chamber under construction at Saclay and possibly a liquid hydrogen bubble chamber of about the size of the 12-ft chamber under construction at Argonne or the 14-ft chamber proposed for Brookhaven. As part of the Brookhaven program additional experimental areas are planned.

Both of the improvement programs have been approved and financed and should be completed by about 1971.

#### The Serpukhov 70-GeV Synchrotron

At Serpukhov, a couple of hours' drive to the south of Moscow, a very impressive laboratory has almost reached the stage of operation of its major facility, a 70-GeV alternating-gradient proton synchrotron. To visitors the machine builders are reluctant to commit themselves to a date of first operation. The visitor is invited to inspect the progress and make his own estimate. The concensus of opinion seems to be that completion should be by the end of this year and that useful beams can be expected during 1968.

The synchrotron in many ways resembles a scaled-up AGS. Its circumference is almost a mile, compared with one-half mile at the AGS. Like the AGS it has twelve superperiods. Its betatron frequency is 9.7 per revolution compared with 8.7 at the AGS. But its designers have been more generous with aperture than we were with the AGS and as a consequence the magnet weighs 12,000 tons, compared with 4000 tons for the AGS.

The Serpukhov builders have been more generous also with enclosed space than we were at the AGS. The spacious magnet tunnel is constructed of prefabricated, curved slabs of concrete. The main experimental area is quite magnificent — about 300 ft across and 500 ft long under an arched roof fabricated of aluminum. This space is all clear; there are no roof supports and an arched crane of almost the full 300-ft span covers the whole area.

The magnet's aluminum windings are powered by four large motor generators whose output is rectified in ignitron banks. The acceleration period is 3.5 seconds and a flat-top time of 1.5 seconds is possible at full field.

The injector is a 100-MeV linear accelerator divided into three tanks. The first tank, whose output is 40 MeV, is completely assembled and is under test.

During the final stages of construction intensive preparation is under way for the experimental program. High energy unseparated beams, both positive and negative, will emerge from internal targets into the area in the experimental hall outside of the ring. Lower energy electrostatically and perhaps rf separated beams will be brought to the area of the hall inside of the synchrotron ring. Members of the Serpukhov staff have visited many laboratories for periods of several months; in fact a whole bubble chamber team spent several months at CERN. An active collaboration is being planned between CERN and Serpukhov and probably joint CERN-Russian teams will do many of the first experiments. Another joint effort has been arranged with France. A liquid hydrogen bubble chamber of about 8000 liters is under construction in Paris and will be taken to Serpukhov for joint use by French and Russian teams. It is to be hoped that similar arrangements can be made so that American high energy physicists also can have a part in pushing our frontiers to higher energies while we await the construction of our own 200-GeV machine.

#### The Novosibirsk 25-GeV Storage Ring

Professor Budker's group at Novosibirsk can be counted on to come up, every couple of years, with some new, ingenious and daring scheme. Not only do they make startling proposals but, in many cases, they have carried them to successful conclusions. The latest of these is a 25-GeV proton-antiproton storage ring.

Many people have pointed out the desirability of a proton-antiproton ring but the argument has always been made that too few antiprotons from a target take up too much phase space, at least at presently attainable proton energies. Professor Budker proposes to shrink the phase space occupied by antiprotons by "cooling" the antiproton beam by an electron beam travelling in the same direction at the same velocity. In the travelling frame of reference the electrons are "hotter" than the antiprotons in the ratio of the masses. Hence, by Coulomb encounters, the oscillations of the antiprotons will gradually damp and the electron oscillations will grow. In about 100 seconds the antiproton beam will reach an acceptable density.

Time does not permit a detailed discussion of the machine. Briefly the protons are accelerated first as negative ions in a 1.5-MeV electrostatic accelerator. Using charge exchange they are injected into an air-core synchrotron 1 m in diameter where they are accelerated as protons to 500 MeV. They are then transferred to the main ring which is shaped like a race track consisting of two semi-circles of 45 m radius (about one-third of the AGS radius) separated by straight sections 40 m long. Acceleration to 25 GeV is slow, taking 50-100 s, because the main magnet is not laminated. At full energy the beam hits a target and the antiprotons produced are transferred into still another race-track-shaped ring of about one-fifth the over-all size of the main ring. Here, in 10-m straight sections, the electron cooling takes place.

After about a day of this some  $10^9$  antiprotons should have been stored. They are then transferred back into the main ring and accelerated along with about  $10^{14}$  protons going in the opposite direction to 25 GeV, at which point colliding beam studies can begin.

This machine complex already is under construction. Its total cost is estimated at between 8 and 10 million rubles.

#### The Japanese and French Design Studies

I shall pass rather quickly over the Japanese 40-GeV and the French 45-GeV studies since both are for relatively conventional alternating-gradient synchrotrons and since, to my knowledge, in neither case has construction yet been authorized.<sup>1</sup> Both groups are quite optimistic, however, about their prospects for eventual authorization.

The Japanese study is centered in Tokyo under the direction of Dr. Suwa, whom many of us came to know and respect during his stay at Argonne. Many capable Japanese physicists and engineers and many institutions are co-operating in the design study.

In France, the correct choice for the next large national machine has been studied for some time. First, a 60-GeV proton synchrotron was favored. Then sentiment in France swung to a 12 to 15 GeV electron synchrotron. Since the first of last year, however, the French have settled on a 45-GeV proton synchrotron. It is not clear what might be the effect on the French project if construction is started at an early date on the European 300-GeV machine.

#### The American 200-GeV Project

The status of the 200-GeV project in the United States was reviewed at the last National Accelerator Conference by Lloyd Smith. At that time the design group at the Lawrence Radiation Laboratory had virtually completed its design study and, as "Look" magazine described it, "the Great Atom Smasher Contest" was just beginning. Over 200 sites had been proposed by state governments, local chambers of commerce, real estate operators, and many other types of proponents. The AEC eliminated over a hundred obviously impossible sites and turned over a list of 85 satisfying certain minimum criteria to a site committee organized by the National Academy of Sciences. After almost a year of intensive work the NAS committee pared the list down to six — one each in New York State, Michigan, Illinois, Wisconsin, Colorado and California. After another nine months of study of these six the AEC announced the final decision. Last December the AEC made public its choice of Weston, the Illinois site, an area of about 7000 acres in the western suburbs of Chicago, about 30 miles southwest of O'Hare Airport.

While the site selection was proceeding, some 46 of the leading American universities were encouraged by the National Academy to form an association to manage the 200-GeV project. This association, modelled in general on the Associated

Universities that manages Brookhaven, is now incorporated as the "Universities Research Association" or URA. Its president is Norman Ramsey of Harvard. URA recently signed an enabling contract with the AEC and then turned to the task of finding a director for the new laboratory.

The AEC has requested \$10 million for the project for FY 1968 to support its final design studies. Hearings were held during February before the Joint Congressional Committee on Atomic Energy and, after exhaustive questioning of the AEC and the officials of URA, the Joint Committee indicated its support for proceeding with the project. Of course, the \$10 million will not become available until it is approved by the Congress sometime next fall. In the meantime the AEC has interim funds to provide for the first requirements of the new laboratory.

Under pressure from the Bureau of the Budget, the AEC has agreed to divide the project into two phases, the first to cost \$240 million instead of the \$350 million estimated by the Berkeley 200-GeV study group. This will present some problems to the new laboratory director and his new staff. It is to be hoped that satisfactory solutions will suggest themselves and that this exciting project can move ahead toward an operating National Accelerator Laboratory.

#### The European 300-GeV Project

Early in 1963, under the aegis of the CERN organization, a "European Committee on Future Accelerators" was formed to study the whole question of future developments in European high energy physics. Under the direction of Professor Amaldi of Rome this committee has been very active, has involved many European physicists, and has issued documents similar in scope and character to the report of the Ramsey Panel and to the AEC's National Policy for High Energy Physics. The leading project in the European program is to be a 300-GeV proton synchrotron and a detailed design study for this machine has been supported at CERN. A design study report was issued by the CERN group at the end of 1964 — it also was discussed at the last Washington accelerator conference by Lloyd Smith. The leaders of the CERN study were K. Johnsen, A. Schoch and C.J. Zilverschoon.

CERN has organized a search for a suitable site for the 300-GeV machine. This search does not seem to have inspired nearly as much public interest as did the American site survey. It has been carried on in a quiet and orderly fashion through the governments of the various countries. Over a hundred sites have been considered; some have been eliminated on technical grounds. Others have been eliminated by the countries themselves in response to a request that, finally, each country should submit not more than one site. At this point nine sites are left. They are as follows: In Austria, a granite site about 55 miles northwest of Vienna; in Belgium, a schist site near the French border and about 60 miles southeast of Brussels; in England, a chalk site in the fens about 30 miles northeast of Cambridge; in France, my favorite

<sup>1</sup>It was learned from Dr. S. Suwa at the Conference that the Japanese project had just been approved.

location about halfway between Nice and Marseilles, virtually in the French Riviera; in Germany, a limestone site about 40 miles northeast of Düsseldorf; in Greece, a site near Athens; in Italy, a limestone site near Trieste and the border of Yugoslavia; in Spain, a granite site 23 miles northwest of Madrid and, finally, in Sweden a granite site near Uppsala. The various sites vary in area between 5 and 10 square miles. You will note that all are rock sites. The CERN group, after much deliberation, has decided on a preference for rock sites in which the machine tunnel will be drilled. They were encouraged in this direction by the cost of recent tunnels drilled in Europe — this cost proved to be relatively low compared with European costs for the sort of tunnel that houses the CERN PS.

At this point an ingenious suggestion was made by Mr. Bannier, the President of the CERN Council. He proposed that an objective evaluation of the various sites could be prepared by a committee of three referees chosen from countries that do not have sites in the final list. These referees have been picked from Denmark, Holland and Switzerland — already they are known as "the three wise men." They will not actually recommend a site; they will prepare a report on the basis of which representatives of each country can propose a list of the three sites that they regard as the best. It is hoped that by September the three most favored sites will be clearly agreed upon and by December of this year it is hoped that a final choice can be made.

It seems likely that the CERN agreement will be revised to include the 300-GeV laboratory and that it will be managed by much the same Council as now manages CERN. Legal experts from England and France are assisting in the preparation of a new draft convention for submission to the member states in September of this year.

If the 300-GeV project is handled on this schedule and if it is quickly approved by enough nations it should proceed on a construction schedule very close behind the envisioned schedule for our 200-GeV machine.

### Conclusion

What can be said of the distant future? After the 200-GeV and the 300-GeV machines only one has had any official blessing. This is the 600 to 1000-GeV accelerator which, according to the National Policy book, is supposed to be started well before the 200-GeV machine is finished. At Brookhaven we are still proceeding on this premise. We are hoping that the development of superconducting devices may be rapid enough that a few years hence construction and operating costs of the super-accelerator can be materially reduced. Our present work along this line looks promising, but some years of work will still be required.

Periodically there are discussions of an intercontinental project. On this point representatives of the Soviet Union have been unwilling to speculate, at least not before the 70-GeV accelerator at Serpukhov is operating. But that date is approaching and possibly intercontinental discussion will be revived between us, Western Europe and the Soviet Union. Perhaps with so powerful an alliance the machine should be for 2000 or 3000 GeV.

Perhaps our theorists will evolve a theory that will explain and predict everything and we shan't need the monster accelerator at all. Progress to date seems to me to indicate that high energy phenomena are still emerging much faster than the theorists can explain them. I think the push for higher and still higher energies will keep us busy for a good many more years.

### References

1. E.D. Courant, E. Keil, and A.M. Sessler, "Effects of the Choice of PS Injector on ISR Capabilities," CERN Internal Report ISR-TH/67-12, January 27, 1967.
2. M.Q. Barton et al., "Design Study for a 1000-MeV Booster Synchrotron Injector for the Brookhaven AGS," BNL Accelerator Dept. Internal Report AADD-127, December 13, 1966.